Glazing of large yachts: ISO 11336; Developments and updates

By Frans Verbaas.

Summary

The design of large yachts has developed rapidly over the last decade and rules and standards have to keep up. In view of this the first part of the popular standard for glazing of large yachts, ISO 11336 was revised and brought up to date. The draft standard was approved by the ISO community with some comments made. After a short overview of the status of the various parts of the standard ISO 11336 the main changes in part 1 are discussed.

1. Introduction

ISO 11336 is an International Standard for water and weathertight glazing on large yachts. It consists of three active parts. The first part, released in 2012 covers the design and mounting of independent glazing; that is applications where the glazing is fitted in a frame that is welded or bolted to the ship's structure. The second part, released in 2020 covers applications where the glazing is bonded directly to the structure. The third part, released in 2019, covers manufacture production control and installation. There are work items for a Part 4, dedicated to advanced calculation methods and for a Part 5, dedicated to applications of glass in balustrades and walkable surfaces.

There are relevant and critical relationships between the parts that need some explanation. Part 1 is intended for use by designers and builders. The intended audience for Part 2 is glazing installation companies. Part 3 is intended to serve manufacturers and inspection bodies. So, where Part 1 does give some limited guidance on bonding, on material qualification, advanced calculation methods and fall protection the details of these subjects are in the other parts. Part 1 gives some qualitative bonding arrangements. Part 2 gives the details of how to calculate the bond line. Part 3 gives details how to make it and how to inspect it. Likewise, Part 4 is intended for use by engineering companies. Part 1 therefore is the cornerstone of the series but it is neither all-covering or fully self-contained.

2. The update of Part 1

One of the aims of the development of the ISO 11336 series was to bring some uniformity the application of the 'Large Commercial Yacht Code', or 'LYC'. ISO 11336:1 was released in 2012; the year that also saw the release of version 3 of LYC, so it should not come as a surprise that the scope of ISO 11336-1:2012 reflects the limits of the scope of LYC at that time. It also reflects the design philosophies of the early 2000's. It takes about 2 years to bring a draft text to a full standard. This means that most of the text of ISO 11336-1:2012 was written well before 2010 and reflects the state of the art of the time it was written.

Since then, the design of architectural glazing has taken huge steps forward. Yacht owners seek similar features on their yachts, calling for features and sizes that went ever further outside of what the workgroup that wrote ISO 11336_1-2012 had in mind when they wrote the text. Windows, that is glass plates closing an opening in a steel or aluminium bulkhead have become an exception. Glass panels extending full deck height have become the norm. Case-by-case engineering solutions framed on the principles of ISO11336-1:2012 were developed between builders, glazing manufacturers and specialists from classification societies who, on behalf of the Flag States, review the design and installation of the glazing. On the whole, this usually worked well, but with glass being used on yachts in ever more challenging and sophisticated ways, it was felt that Part 1 needed to be updated to keep up with this evolution

The opportunity came in quarter 3 of 2017. At that time ISO11336-1:2012 was subject to its 5-year systematic review. The ISO TC8/SC12 secretariat, after some deliberations, decided to charge its workgroup number 2, who wrote the original text, to carry out an update. This WG2 at the time concentrated on completing Parts 2 and 3. Work on the Part 1 update started in earnest in the course of 2019 but it grinded to a halt early 2020 due to Covid-19 situation. In the autumn of 2020, the work resumed in on-line sessions. As the work progressed it became clear that simple patching would not solve the issues experienced in application of the 2012 version to modern yachts so it all took longer than expected. In March 2022 the draft text was submitted to ISO secretariat. A DIS ballot was initiated. It was concluded on 11 August 2022.

The document voted on and discussed in this paper will be referred to here as the 2022 DIS. The expectation is that the new version will be issued as an FDIS in March 2023 and could consequently become a full ISO standard in March 2024.

The changes in the 2022 DIS relative to the 2012 version feature an extension of scope, some error corrections, but most of all technical updates allowing a more rational and state-of-the-art glazing design. Some of the key changes are discussed in this paper.

3. Extensions of the scope of the standard:

3.1 Applicability to yachts of more than 3000 GT.

During the development of what later became ISO 11336:2012 was developed, the scope of the 'Large Yacht Code' then in force was limited to 3000 GT. This limit has been removed in later versions of the Large Yacht Code. Its successor REG Yacht Code Part A also does not have such limitation.

The tables 1, 2 and 4 in ISO 11336:2012 gave requirements in a table as a function of ship's length between 24 m and 90 m. This latter value reflected about that 3000 GT limit.

In the 2022 DIS the tables are extended to cover yachts with a length up to 300 m and above, keeping the same trends. For portlights (Table 4) reference is made to the standards for design pressures for commercial vessels.

3.2 Coverage of yachts carrying more than 12 passengers.

Flags consider yachts carrying more than 12 passengers to be passenger ships, which are subject to a much more complicated set of international regulations. Most striking differences are found in the requirements for fire safety, escape routes, and so on.

ISO 11336-1 is related solely to water/weathertight integrity. Fire safety is **not** covered in this standard. There is no reason why the requirements for water/weathertight integrity for yachts carrying more than 12 passengers would need to be different from the requirements for yachts with not more than 12 passengers. It was therefore decided to extend the scope of the 2022 DIS to cover yachts with more than 12 passengers, but to *explicitly exclude any fire safety aspects*.

The number of builders of yachts carrying more than 12 passengers is very small. The aim of ISO 11336-1 is to provide an easy-to-use tool for the main segment of the market. Incorporating 'Passenger yacht' fire safety aspects in this International Standard would make it unnecessarily complicated for the majority of the users.

3.3 Coverage of other glazing materials

The 2012 version covered glazing made from Thermally Toughened Glass (TTG) and Chemically Strengthened Glass (CSG). The 2022 DIS covers also panes containing Annealed Glass (AG), Heat Strengthened Glass (HSG) and Alkali Aluminosilicate glass. Annealed glass was added because some available coatings are hardly appliable in combination with thermal or chemical strengthening. Heat Strengthened glass was added because it has much less fragmentation and therefore much better post-failure properties than TTG. Alkali Aluminosilicate glass, known from consumer electronics devices, is a promising material. Once it becomes available in suitable thickness, size, and price it can be expected to appear in yacht glazing.

3.4 Size of hull windows (not extended)

The upper limit of 0.85 m^2 for glazed openings in the hull is not changed. This may come as a disappointment to some but extending the scope of the standard to cover this would require extensive work on establishing criteria for the permissible deformation of the supporting structure and mounting methods to deal with these. This would involve consideration of structural hull arrangements, global strength, and more. It simply is not a topic that is suitable to be covered by an international standard dedicated to glazing. This does not mean that hull openings larger than 0.85 m^2 would be forbidden. It is just that ISO 11336-1 cannot be used to justify the design.

4. Changes in the design load calculation.

4.1 Reduction of the design pressure for glazing on side openings of in type B superstructures (protecting a volume considered buoyant.

The pressures given in table 4 of the 2012 version were considered too onerous for superstructure side positions which have greater distance above the waterline than the hull openings. In the 2022 DIS this is accounted for via a 50% reduction factor on the design pressure values.

4.2 Reduction of house side design pressure with height above the waterline

The 2012 version featured a minimum design pressure for fronts and a minimum pressure for other locations. This minimum pressure was to be applied irrespective of the height above the deck topping the buoyant volume. This usually resulted in glazing on the sun deck aft to be designed to the same pressure as side windows on the main deck. The 2022 DIS implements a procedure like the one in Lloyd's Register's Rules for Passenger ships. Up to the height where the calculated pressure reaches the minimum pressure nothing changes. Above that level the 2012 version dictated a constant pressure, but in the 2022 DIS the pressure is tapered over 5 meters vertical height to reach a minimum at 3.5 kPa and 7 kPa for glazing in higher tiers in sides and fronts respectively. The 3.5 kPa design pressure is commensurate with the 50 years return wind load used in architecture in exposed North Sea shore locations.

4.3 Single continuous model for the design pressure

The 2012 version design pressure calculation featured distinct factor tables for different positions like side, aft and front and different 'tiers', leading to discussions and sometimes drastic changes in design conditions depending which table was applied. The 2022 DIS features a continuous envelope based on the orientation angles and position of the pane only. It thus does support automatic assignment of the design pressure based on a CAD model. Figure 1 shows the window orientation angles.

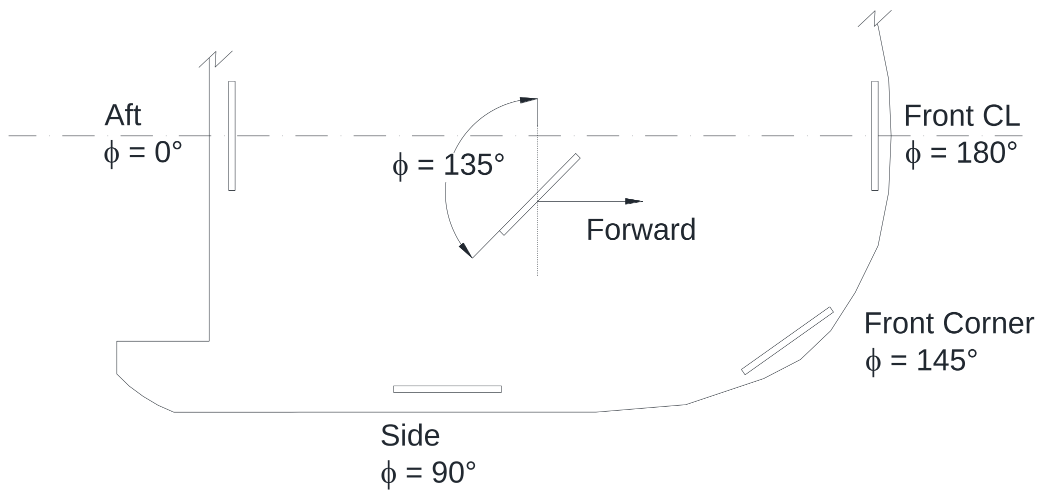

Figure 1 Window orientation angles

5. Changes in the downflooding risk management (formerly known as 'storm covers')

The 2022 DIS maintains and extends the philosophy of the 2012 version but it changes the emphasis to laminated glazing of ‘enhanced construction’. Traditional arrangements with storm covers would still be acceptable under the standard but they do not anymore represent the base approach.

Monolithic windowpanes made in CSG, HSG or AG would represent a serious risk of injury from shards so sheets made of these materials can only be applied in laminated cross sections. When made in TSG glazing could be of monolithic construction but for yacht windows in the size and surface quality now required only laminated construction is feasible. The ‘design enhancement’ can be expressed as a multiplier on the design pressure. The 2022 DIS proposes to use factor 1.5 for positions where Flag requires storm covers to be fitted and factor 1.0 for all other locations.

To ensure the panes of ‘enhanced construction’ do what they are intended for, the 2022 DIS adds requirements for the performance of the glazing after failure of one ply of the laminate. It shall be capable of withstanding the design pressure with a unit factor of safety and provide protection against ingress of water for a period needed for the crew to detect the failure and make fixes to limit the effects.

Annex 1 to this paper gives some more considerations on the subject.

6. Material factors and default material properties consistent with industry standards

In the 2022 DIS some default material properties were corrected to line up with industry production standards and to ensure consistent application of engineering methods.

6.1 Characteristic Failure Strength of TSG glass

Soon after the release of the 2012 version there was feedback from glass manufacturers that the strength of TSG material quoted (160 MPa) was not consistent with industry production standards that use 120 MPa. Reverse-engineering results from pressure tests on marine glazing indeed revealed that 120 MPa gives a better estimate of the 5% lower tail of the distribution of the load bearing capacity. There was no evidence designs made to the 2012 version were unsafe so it was decided to keep the basis of design the same but to reduce the design factor. The 2012 version specified a design factor 4, leading to a design stress of 160 MPa/4 = 40 MPa. The 2024 version, consistent with industry standards like EN 12150, specifies a CFS of 120 MPa, to be used in conjunction with a design factor 3. This again leads to a design stress of 40 MPa.

6.2 *Shear modulus of PVB interlayer material*

The 2012 version gave, consistent with manufacturer’s specifications at the time, a default of 1.6 MPa for the shear modulus of common PVB interlayer at 25 degrees Celsius and 60 seconds load duration. Since 2012 the manufacturers of interlayer materials changed the definitions in their material property sheets and 1.6 MPa would now be associated with 10 seconds load duration. The 2022 DIS therefore calls for properties at 25 degrees and 10 seconds load duration to be used. This shorter period also better represents the wave period at sea and therefore is considered more representative for sea loads in the quasi-static approach applied in the standard.

7. Changes in the scantling calculation methods

The 2012 version only recognized traditional linear plate theory for qualification of a design. In exceptional cases proof by testing was supported. The 2022 DIS still features this but allows to use FEM and non-linear analytic methods as an alternative. Under certain conditions the effect of the gas in an insulated glazing unit can be considered.

The 2022 DIS does not give extensive descriptions of assessment methods. It gives some references and clauses to enable use of Part 4 of ISO 11336 when it becomes available.

7.1 Non-linear analytic calculation methods for plates with large deflections.

The results of traditional linear plate theory are usable as so long as the deflection is small. However, when the deflection is more than, typically, the thickness of the plate linear calculation quickly become very conservative.

The method was suitable for the assessment of traditional monolithic TSG glazing of sizes as per the traditional marine glazing standards. For the assessment of now commonly occurring full height panes of laminated high strength glazing it is certainly not the most suitable method, as is illustrated in Figure 2. For this example 15 kPa the linear method over-predicts stress and deflection almost by a factor 2.

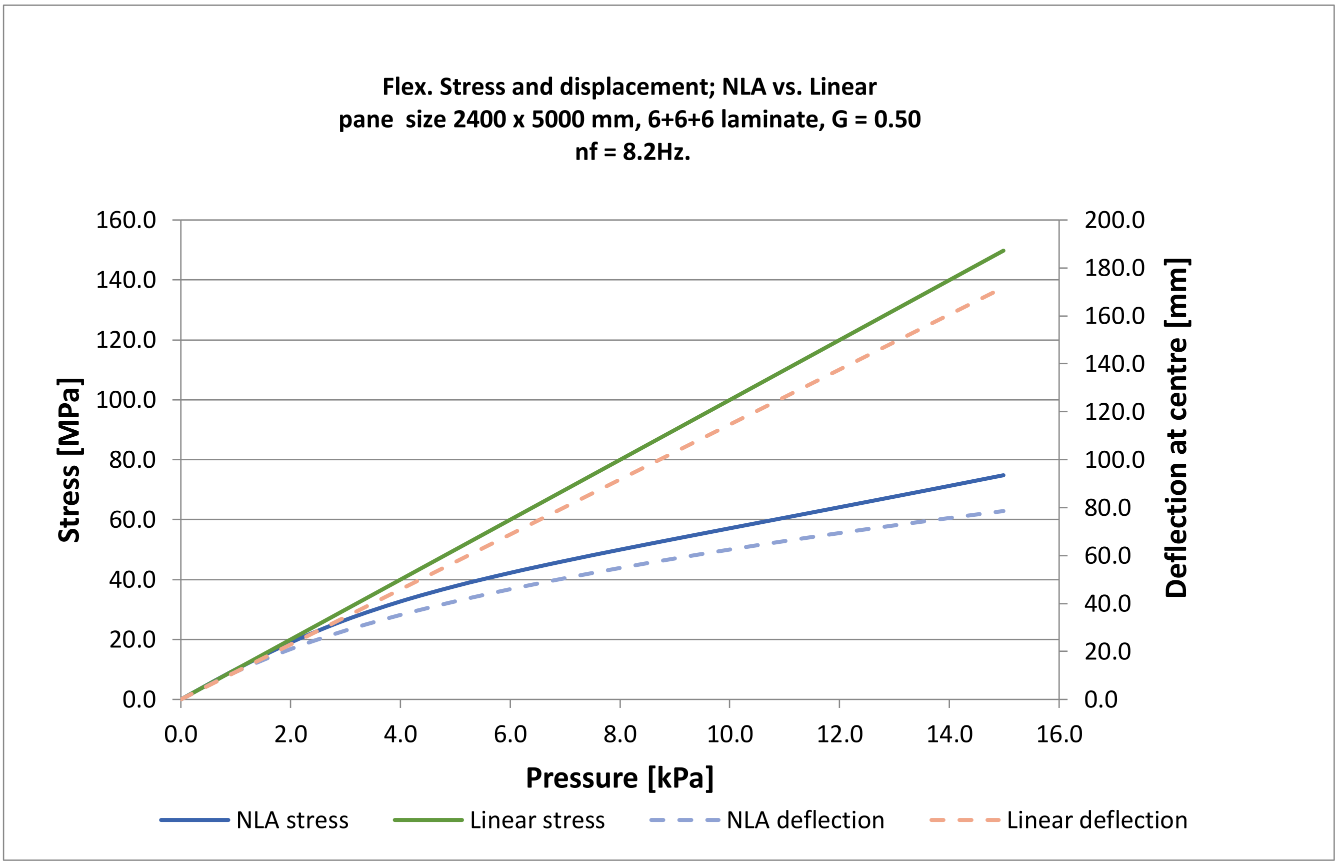

Figure 2 Comparison results NLA calculation versus non-linear.

The 2022 DIS does not prescribe a specific method to be used but it mentions the method given in the annex of EN 16612. This method has the same input parameters as the linear method given in the 2012 version and it can easily be implemented in a spreadsheet. Tests carried out by Lloyd's Register and by the workgroup showed the results so obtained are in good correlation with the results of much more elaborate non-linear large deflection FEM calculations. Also, the results of the method have been found consistent with the statistics of pressure test results. The application is limited to flat rectangular panes, simply supported on all edges.

7.2 Calculation via FEM

First a word of warning should be given. FEM calculations on laminated glazing are in no way straight-forward. The modelling and the interpretation of the result require expert knowledge and it should be done with great care.

A particular warning should be given about the use of plate or shell elements with an 'equivalent thickness' of the laminated glazing. This is suitable only for flat glazing simply supported at the edges. In such a plate, the maximum bending moment occurs in the middle, where the shear force in negligible, of course, but well away from the location with maximum shear force. On a clamped edge or a support not at the edge, the locations of maximum shear and maximum bending coincide. High shear stress in a laminate means high shear deformation in the interlayer so low collaboration between the plies. Therefore, the actual 'effective thickness' at that location will be significantly smaller and stresses from the FEM model will be significantly under-estimated.

As mentioned, a Part 4 for ISO11336, dedicated to FEM and other 'advanced calculation methods' is in preparation, but pending completion an Annex J was introduced in the 2022 DIS version giving some of the main do's and the don'ts. For the validation of FEM tools, a list of test cases with expected results and permitted deviations is provided. It is expected that, in near future, the FEM approach to glazing design will be expanded by situations were combined load or different edge constraints situations will force in that direction. On top of that some "glazing facades" concepts introduce in-plane loading, and deflection of the support may require global FEM evaluation of the supporting structure. These last aspects of glazing design again are outside the scope of a glazing standard and they are not covered by the 2022 DIS version.

7.3 Taking the effect of compressed gas in IGU cavity into account

For large size panes of high strength laminated glass applied on yachts the effect of gas compression in the chamber of insulated glazing can no longer be ignored so it was introduced in the 2022 DIS.

To get an understanding of the effect assume an IGU in an equilibrium situation. The glass panes are flat and the gas in the cavity has the same atmospheric pressure as outside the IGU. Then assume an outside pressure deforms the outside pane such that the displacement in the centre equals the depth of the cavity. If the inside pane were rigid, the gas in the cavity would be reduced in volume to about 50% of the original volume. The pressure in the cavity would rise to twice the atmospheric pressure, so about 2 bar = 200 kPa. This is well in above of the pressures considered in yacht glazing design. Of course, in reality the inside pane is not rigid and it will deflect under the pressure of the gas. The pressure of the gas will be less than the deforming pressure on the outside, but more than the atmospheric pressure acting on the other side of the inner pane. A part of the load on the outside pane therefore is carried over on the inside pane, and this can be taken into account.

The amount of load sharing depends on the ratio of the stiffness of the panes but it can be quite significant. The computation is not easy but it is codified in EN19100 and EN16612. In the 2022 DIS it was implemented as one of the alternative engineering approaches that could be followed under the standard.

8. **Changes regarding glazing arrangements**

8.1 Fall protection

In the 2022 version of this standard the requirements for glazing in higher tiers was reduced significantly. Also yacht designs at the time tended to have full glass walls, acting as bulkhead. It was therefore considered necessary to include a requirement for fall protection. The requirements in Eurocodes for parapets were taken as a reference. It was considered that yachts go to sea with a reduced number of people on board, so crowding is unlikely to occur, but the ship may move with the waves, putting higher demands on protection than would be needed in a land-based application.

It was also considered that when the ship is in port, there is no limit to the number of people, and crowding may occur. For glass walls and parapets bounding places where crowding may occur Eurocode EN1991-1 prescribes design loads 50% higher than in locations where crowding is unlikely.

With a 50% addition for shipboard use therefore the requirements for both seagoing service and party-in-port service can be considered satisfied. A similar solution has been in use for several years now for glass bulwarks.

8.2 Secondary barriers in lieu of deadlights

The 2012 version unconditionally required all hull portlights to be fitted with deadlights made from steel or, novelty at the time, from aluminium or even FRP.

Deadlight plates for 0.85 m^2 portholes are difficult to handle and the arrangements to mount them are difficult to combine with the aesthetics of a yacht's guest accommodation.

Responding to demands from both the industry and the flag states the 2022 DIS proposes criteria under which the Flag Authority could agree to use glazed secondary barriers. Some key points:

- Yacht must comply with Flag damage stability requirements
- Permanently mounted to the ship's structure

- No single failure of any component, including bond lines, should lead to loss of the watertightness. This means the outer glazing and the inner glazing should not share the same bond line.

- The glazing cross section and mounting are to be qualified via a series of drop tests with a heavy (60 kg, typical) impactor headed by a hexagon bolt head spanner size 19 mm hitting the glazing with 1800 J kinetic energy. After the impact the samples must successfully pass a pressure test.

The drop test energy for this impactor was selected to the satisfaction of Flag representatives.

The 2022 DIS calls for a minimum of three samples with identical frame and glass composition to be tested. For hull glazing as covered by the standard, up to 0.85 m2, the 2022 DIS suggests a typical size range for the samples: 400mm by 400mm (AR =1); 1100mm by 800mm (AR=1.4); 1100mm by 400mm (AR = 2.75).

It is emphasized that these sample sizes were not selected to represent sizes of hull glazing. They were selected to cover a range of impact conditions. The actual performance of the glass in the pressure test will depend on the combination of the level of damage caused by the impact and the location of the impact damage. Within the example size range the smaller panel, more stiff than the others, will see the most severe surface load under the impactor head and therefore it is expected to suffer the most severe surface damage. On the other hand, relative to its size and glass thickness, it will see the lowest flexural bending moments when subjected to the test pressure. The test of this panel could account for impacts occurring near a side or a corner, where the glass panel is stiff against impact but also only moderately loaded when the glass is under pressure. The test on the largest sample represents the case of an impact in the centre of the panel, where the response of the panel to the impact lateral load is more elastic so one can expect less surface damage, but that damage is in the location where the bending load under the pressure test will be the largest. The intermediate size panel would show performance for cases where a medium degree of damage can be expected and a medium load level.

Annex 2 gives a more in-depth considerations on the secondary barriers.

9. Miscellaneous clarifications and improvements

The 2022 DIS gives various changes that aim to clarify things or make the standard more simple to use.

9.1 expressions to approximate tables

In the 2022 DIS most of the tables now come with equations that approximate the table values with sufficient accuracy. This makes it easier to implement the calculations in a spreadsheet tool. Figure 3 gives an example of a table with a matching expression.

Lengt h L m	24	30	40	50	60	70	80	90	100	120	140	200	300
Factor f	1,18	1,72	2,57	3,36	4,09	4,76	5,38	5.94	6,45	7,33	8.04	9,34	10,0
	approximation: $f = 0.4284(L/100)^3 - 3.6865(L/100)^2 + 10.951(l/100) - 1.244$												

Figure 3 Example of a table with expression for approximation of table value

9.2 Informative annex with changes

For the ease of the user the 2022 DIS features an Annex I is added in which most of the changes relative to the 2012 version are described.

10. Conclusion

The team that wrote the very successful ISO11336-1:2012 standard have collected and arranged their experience gained in more than a decade of application into a new draft standard. The changes reflect the trends in glass technology and yacht building so it is as ready as it can be to serve another decade.

The approval process at ISO is on-going. The project schedule suggests an FDIS will become available in 2023.

With the 2022 DIS ISO11336-1 has moved in the direction of an engineering standard for yacht glazing. Relative to the prescriptive approach of the 2012 version this gives greater freedom to the designer but also it puts more responsibility on their shoulders.

Selected Bibliography:

ISO 11336-1:2012, Large yachts — Strength, weathertightness and watertightness of glazed openings — Part 1: Design criteria, materials, framing and testing of independent glazed openings

EN 16612 - Glass in building. Determination of the lateral load resistance of glass panes by calculation

EN 1990_Eurocode - Basis of Structural Design. Brussels: CEN.

EN 19100-1 - Eurocode 11 Eurocode 11 — Design of glass structures - Part 1: Basis of design and materials Brussels: CEN

EN 19100-2 Eurocode 11 Eurocode 11 — Design of glass structures - Part 2: Design of out-of-plane loaded glass components: Brussels: CEN

Consiglio Nazionale Delle Richerge. (2013). CNR-DT 210/2013: Guide for the Design, Construction and Control of Buildings with Structural Glass Elements Rome: CNR.

Feldmann, M. K. (2014). Guidance for European Structural Design of Glass Components. Luxemburg: Publications Office European Union.

Verbaas, F. (2016). From Simple Window to Structural Material. SWZ|Maritime(February; March).

Annex 1 On managing the risk of water ingress

The International Convention on Load Lines (ICLL) recognizes the vulnerability of glazed openings for accidental damage. When these openings are in end bulkheads of enclosed superstructures or in other bulkheads protecting access into the hull, failure of the appliance could lead to water ingress. They therefore require the appliances are fitted with an additional protection in the form of external storm covers that protect the glazing against mechanical damage and limit the ingress of water in the case the glass is broken.

The Large Yacht Codes copied this requirement, but they allow alternative solutions featuring laminated glazing of 'enhanced construction':

> *Where windows are of laminated construction and their equivalent toughened safety glass thickness exceeds the requirements of the applied standard by a minimum of 30%, storm shutters need not be carried …..*

This quickly became the standard method on yachts to manage the downflooding risk. The glass had to meet the requirements of a recognized standard, but where this was not the case it could be qualified via testing. For glazing to be used in locations where no 'storm shutters' were required a test pressure of 2.5 times the design pressure was to be used. For glazing of 'enhanced construction' this was 4 times the design pressure. It could be concluded that the Code expected the strength of 'enhanced thickness' glazing to be 4/2.5 = 1.6 times the strength of non-enhanced glazing. This factor 1.6 is not too far off from the $1.3^2 = 1.69$ times that follows from the 30% thickness increase.

In the 2012 version, based on observations on North Sea supply vessels, the design enhancement was defined as 50% increase in design pressure, which would be consistent with a test pressure 3.75 times the design pressure.

Decades of yacht service has seen very few glazing failures. Where failures occur, they can usually be tracked to manufacture faults, contact with sharp objects or failure of the mounting. Failure of glazing by over-pressure is very uncommon. For the evaluation of the design of a cross section it therefore would be better to look at the residual strength of the laminated glazing after failure of one ply.

For a laminate with two plies of same thickness, the residual strength after loss of one ply is 50% of the original strength calculated without collaboration and 25% of the original strength calculated with full collaboration. Actual values for practical cases will be somewhere in-between these two limit cases. So, if the original laminated pane was demonstrated to be strong enough to withstand 4 times the design pressure, even when the glass cross section was designed based on a high degree of collaboration between the plies, the damaged pane with one intact ply and one broken ply can still be expected to have a factor of safety greater than or equal to unity.

For laminates with three or more plies the above could be applied to reconsider the engineering factor between stress at design pressure and characteristic failure stress. The 2022 DIS does not feature this.

The engineering factor should be chosen with care and attention for the risk of downflooding. For example: glazing located just outside the zone where strengthening is required and protecting a large staircase that gives direct access below some margin in the design could be recommended.

Annex 2 Some thoughts on deadlights

This standard describes glazed closing appliances for hull openings that are, by dimension, material and design, outside the prescriptive framework that ICLL Regulation 23 dealing with 'Scuttles, windows and skylights' is based on. The best fit for the closing appliances we look at on yachts is Regulation 21 'cargo ports and other similar openings'. This section gives a performance criterion. It reads as follows:

> *Cargo ports and other similar openings in the sides of ships below the freeboard deck shall be fitted with doors so designed as to ensure the same watertightness and structural integrity as the surrounding shell plating.*

In a ship in which the lower deck has been designated as the freeboard deck, the means of closing openings in the shell plating below the weather deck but above the freeboard deck is governed by the IACS interpretation: *‘should be so designed as to ensure integrity against the sea commensurate with the surrounding shell plating, having regard to the position of the opening in relation to the waterline.’*

The criterion in the 2022 DIS for the secondary barriers therefore was selected to ensure integrity commensurate with the surrounding shell plating, both in terms of resistance to uniform pressure and resistance to penetration by objects with an average corner radius comparable to plate thickness.

Resistance to uniform pressure in the intact state was covered as elsewhere in the standard. For impact resistance a formulation was to be found.

The actual thickness of shell plating depends on the distance between the members of the supporting framing. Bases on minimal thickness criteria by classification Rules, it was decided to frame the impact resistance criterion on a standard plate thickness of 6 mm and mild steel construction. These minimal thickness criteria aim to ensure a degree of resistance to local loads.

There was anecdotic but undocumented evidence available that an impactor of 60 kg headed by a 19 mm spanner size hexagon bolthead, when dropped from 3 m height would just penetrate a 6 mm steel plate semi-fixed to a frame 1.0x1.0 m, when impact was in the middle of the plate. The corresponding energy would be: 60 kg * 9.81 m/s2 * 3.0 m = ~1800 J. The corresponding velocity can be calculated as 7.7 m/s.

The velocity of 7.7 m/s was considered not un-typical for the velocity a piece of debris could develop in a wave crest. To allow some freedom in the execution of the test the 2022 DIS specifies a velocity range of 5 m/s to 10 m/s. Corresponding drop height are 1.27 m and 5.1 m respectively. The mass of the impactor has to be adjusted to ensure the impact energy of 1800 Joules.

The actual shell thickness of large yachts is often selected as more than 6 mm for other reasons, such as fairness of the hull and resistance against buckling. Even if an impact of the magnitude assumed would not penetrate these thicker shells, it would leave a severe dent in the plate. Yachts in their operation do not regularly have the shell severely dented. This would indicate an impact event of a magnitude is assumed that is not occurring frequently and the probability of such happening on a damaged porthole is very small. It also tells us the energy assumption is on the safe side and the velocity assumption is realistic.

The amount of surface damage and loss of strength will increase with increasing contact force between the impactor and the glass. Damage development is not a continuous process. A glass ply either breaks or it does not break. This holds for any glass composition, but most strongly for laminates built from TTG, where breakage of a ply means an extra amount of potentially damaging energy is released into the system. The test conditions must therefore necessarily be conservative.